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MUNICIPAL AND INDUSTRIAL WATER REQUIREMENTS SOMERVILLE RESERVOIR YEGUA CREEK TEXAS

Public Health Service
Dallas, Texas

April 1961

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MUNICIPAL AND INDUSTRIAL WATER REQUIREMENTS

SOMERVILLE RESERVOIR

YEGUA CREEK

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DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service, Region VII
Dallas, Texas

In Cooperation with the

DEPARTMENT OF THE ARMY
U. S. Army Engineer District - Fort Worth, Texas

APRIL 1961

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I. INTRODUCTION

Authority

In a letter dated June 23, 1959, the District Engineer, Fort Worth District, Corps of Engineers, requested the Region VII Office, Public Health Service, to furnish an evaluation report on the Somerville project.

This study was made in accordance with the provisions of the Memorandum of Agreement dated November 4, 1958, between the Department of the Army and the Department of Health, Education, and Welfare. The Memorandum established working arrangements between the Public Health Service and the Corps of Engineers for implementation of the Water Supply Act of 1958.

Purpose and Scope

The purpose of this study report is twofold. First, a recommendation is to be made of the prospective needs for municipal and industrial water supply which might be satisfied from the proposed Somerville Reservoir project. Second, it must be determined whether or not it is desirable (from the standpoints of economics and water quantity and quality) to meet these prospective needs from the Somerville project.

Projections of future populations, industrial expansion, and water requirements were made for the entire lower Brazos River Basin. Consideration was also given to how the future water requirements of this area may best be met.

This report for Yegua Creek and Somerville Reservoir is the third in a series of three such reports on projects being studied for the tributaries of the lower Brazos River. The other reports are concerned with projects located on the San Gabriel and Navasota Rivers. These three projects are related from a water supply standpoint, in that a common market for municipal and industrial water will exist in the lower Brazos River Basin.

Acknowledgments

The cooperation and assistance of those listed below in providing information necessary to the preparation of this report are appreciatively acknowledged.

Geological Survey, U. S. Department of the Interior, Austin, Texas
U. S. Study Commission - Texas, Houston, Texas
Texas State Department of Health, Austin, Texas
Texas Board of Water Engineers, Austin, Texas
Brazos River Authority, Waco, Texas
Company Representatives, Dow Chemical Company, Freeport, Texas

In addition to those listed above, many officials of numerous municipalities in the study area provided information and assistance extremely helpful in preparing this study. Appreciation is extended to those people for their help and cooperation.

II. SUMMARY AND CONCLUSIONS

Summary

1. Somerville Reservoir would be located in Burleson, Lee, and Washington Counties, Texas, at river mile 20 of Yegua Creek, about 2 miles south of the city of Somerville.

2. The length of the study area runs from Waco to Freeport. The east-west boundaries generally follow the limits of the lower Brazos River Basin.

3. Urban centers within the study area which exceeded 10,000 population in 1960 were Temple, Killeen, Bryan, College Station, Waco, and Freeport. These cities, along with the petrochemical industry in Freeport and the manufacturing activities located near Waco, will be the major water users and waste producers in the study area.

4. The aggregrate firm yield from surface reservoirs, existing and proposed, totals 538 mgd (million gallons per day). The maximum capability of groundwater aquifers in the study area is unknown, but investigations indicate that a total of approximately 117 mgd may be developed to satisfy projected municipal and industrial demands.

5. In general, water in Somerville Reservoir will be of sufficiently good quality to make it suitable for municipal and industrial purposes.

6. The quality of water in the Brazos River above Lake Whitney makes questionable its suitability for general municipal and industrial use until a satisfactory solution is found to the problem caused by mineral contamination from natural sources.

Conclusions

1. The projected municipal population of the study area will reach 1,143,200 by the year 2010.

2. A projected municipal and industrial water demand of 1,102 mgd will develop by 2010 in the lower Brazos River area.

3. Comparison of the 655 mgd of total water available from all surface and ground water sources with the projected requirements of 1,102 mgd, reveals a supply deficit of 447 mgd.

4. The water supply deficit indicated above is partially offset by the fact that the figures represent gross takeout from sources, a portion of which will be returned to the stream for subsequent re-use. However, this compensating effect is minimized in this study because approximately 800 mgd of the total demands of the area are expected to be required near the mouth of the river. Additional measures will be required to increase the dependable supply, if growth is to occur as projected.

5. Storage for water supply, in the maximum amounts which can be economically provided, should be included in the proposed Somerville Reservoir project.

6. Based on economic analysis of a regional alternative plan of water supply, the average 1965 values for the water supply storage of the six reservoirs considered in this study are shown below. Further details are given in the last chapter of this report.

Reservoir	Average Annual 1965 Value	Yield (mgd)	1965 Value (¢/1,000 Gal. of Yield)
Stillhouse Hollow	$ 610,000	63	2.66
Somerville	526,000	36	4.01
North San Gabriel	347,000	19	5.00
Millican	963,000	226	1.17
South San Gabriel	116,000	11	2.89
Laneport	365,000	23	4.35
SUM OR AVERAGE	$2,927,000	378	2.12

III. DESCRIPTION OF PROJECT

Location

Yegua Creek, a tributary of the Brazos River, originates in the western part of Lee County in central Texas. It flows eastward from its source for about 90 miles to its confluence with the Brazos River.

Major tributaries of Yegua Creek are Davidson, Cedar, and Nails Creeks.

The watershed has an area of more than 1,000 square miles, a length of approximately 62 miles, and a maximum width of approximately 32 miles. Portions of the following six Texas counties fall within the watershed boundaries: Williamson, Milam, Bastrop, Lee, Washington, and Burleson. Most of the watershed's area is coincidential to the areas of Burleson and Lee Counties.

As shown on Figure 1, Somerville Reservoir will be located in Burleson, Lee, and Washington Counties, Texas, at river mile 20 of Yegua Creek, about two miles south of the city of Somerville.

Stream Flow [1/]

Discharge has been observed by the U. S. Geological Survey at the Somerville gage in the Yegua Creek watershed since May 1924. This gage is located at mile 18.4 of Yegua Creek. The average annual runoff for the period May 1924 through September 1959 was 283 cfs (cubic feet per second). For this same period, no flow was observed several times for periods of one or more months. The maximum flow recorded was 56,800 cfs on July 1, 1940. Practically all of the flow of Yegua Creek is derived from surface runoff, there being little supplied from springs or seepage.

Water Quality

The present quality of Yegua Creek water is generally considered to be good. From two samples of this water, which were taken at very low stream flows, analyses show the total hardness and sulfate concentrations to be approximately 390 ppm (parts per million) as $CaCO_3$ and 280 ppm respectively. These concentrations are rather high, but with proper treatment they can be lowered to a point that will make the water generally acceptable for municipal and industrial uses. Also, it is believed that the concentrations

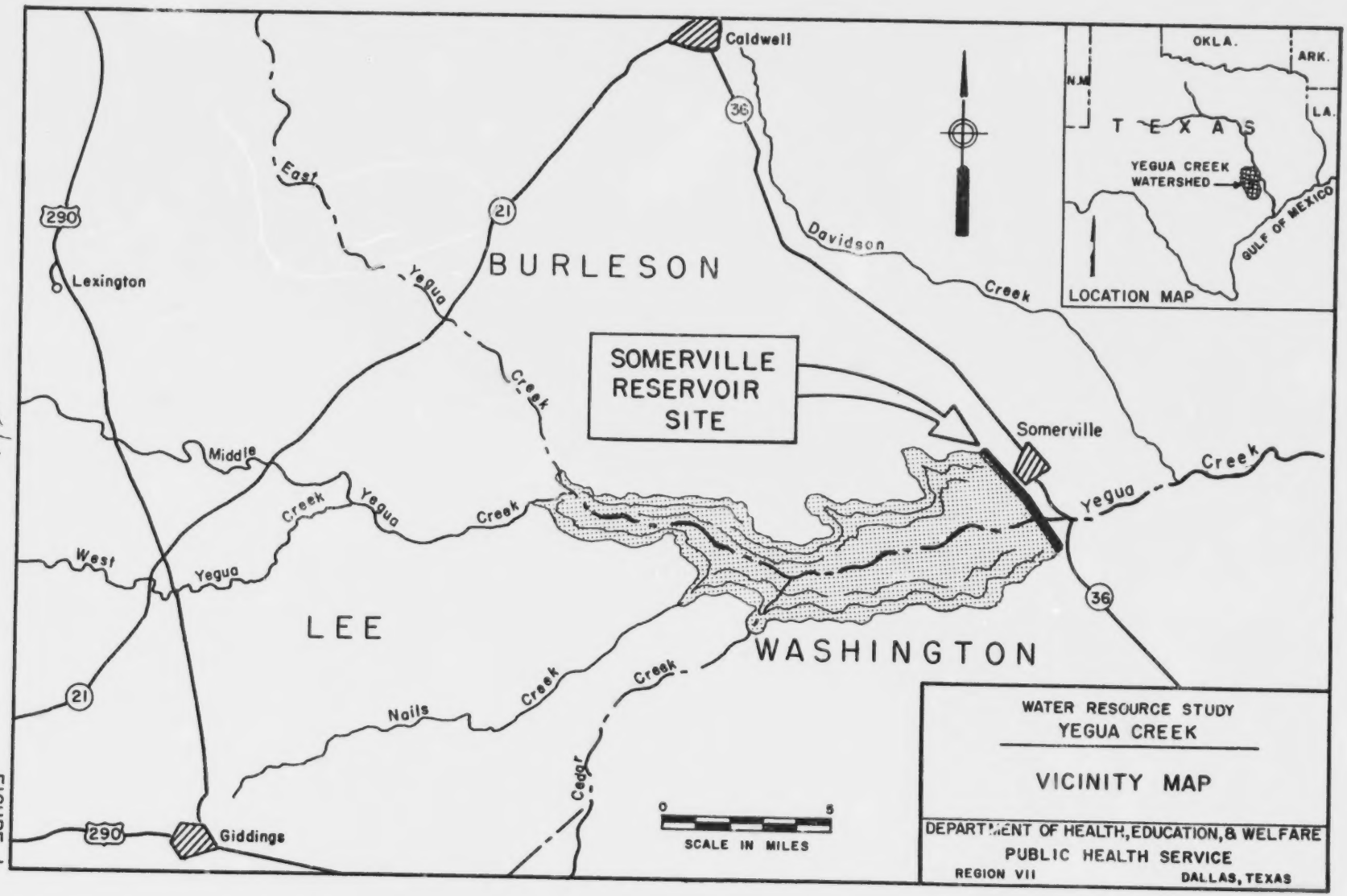

Caldwell
36
East
Yegua
Creek
21
BURLESON
Davidson
Creek
290
Lexington
SOMERVILLE
RESERVOIR
SITE
Somerville
Middle
Creek
Yegua
Creek
Yegua
Creek
West
Yegua
LEE
WASHINGTON
36
21
Nails
Creek
Creek
Cedar
290
Giddings
0
5
SCALE IN MILES
OKLA.
ARK.
N.M.
LA.
T E X A S
YEGUA CREEK
WATERSHED
GULF OF MEXICO
LOCATION MAP
WATER RESOURCE STUDY
YEGUA CREEK
VICINITY MAP
DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII
DALLAS, TEXAS

FIGURE 1

of these mineral constituents will be considerably less during periods of average or higher flow. Information obtained from the U. S. Geological Survey indicates that the water stored in a reservoir on Yegua Creek probably will contain less than 500 ppm total dissolved solids.

Other streams, whose watersheds cover the same geologic outcrops as the Yegua Creek watershed, have been chemically analyzed and the resultant data show the water of all these streams to be of good quality. Examples of such neighboring streams are Cummins Creek and the Navasota River.

The Texas State Department of Health, as part of a statewide water quality survey, has been taking biweekly stream samples at the intersection of U. S. Highway 190 and the Navasota River. Analyses of samples taken at this station are summarized in Table 1. The concentration of chlorides has exceeded 250 ppm in 12 per cent of the samples. This is due, in part, to oil field brines entering the river above the sampling point. The concentration of total dissolved solids exceeded 500 ppm in 19 per cent of the samples and exceeded 1,000 ppm in 2 per cent of the samples.

Table 1

Chemical Quality - Navasota River at Bridge On U. S. Highway 190

(Period of Record - October 17, 1957 through April 11, 1960)

	Total Dissolved Solids (ppm)	Chlorides (ppm)	Sulfates (ppm)
Maximum	1,200	460	100
Minimum	43	12	8
Arithmetic Average	407	131	41

The chemical quality of the water in the main stem of the Brazos River will be discussed later in this report, but it is important to note at this time the improvement in its quality as this water flows to the Gulf of Mexico and is diluted with water of good quality from tributary streams, such as Yegua Creek, the Navasota River, and the San Gabriel River. Chemical quality records show reductions of 28 per cent and 55 per cent respectively in the concentrations of chlorides and sulfates as Brazos River water moves from Whitney to Richmond, Texas. Currently, the unregulated stream

flows of Yegua Creek contribute little to the flow in the main channel of the Brazos during dry-weather periods. It is concluded that an impoundment on Yegua Creek would provide greater amounts of dilution flow, during dry weather, than under natural, unregulated conditions and this additional water would serve to improve the chemical quality of the Brazos through lowering the concentrations of chlorides and sulfates.

Pertinent Data

Somerville Reservoir will consist of an earthen embankment approximately 20,210 feet long, a 1,250 foot uncontrolled spillway in a saddle on the right abutment, and an earthen dike which will project from the spillway for approximately 4,715 feet in a southeasterly direction. The outlet works, as presently planned, will consist of one 10 foot diameter conduit controlled by two 5 foot by 10 foot gates. The invert elevation of this conduit is approximately 32 feet below the bottom elevation of the conservation pool. The volumes of storage are: sediment reserve, 25,900 acre-feet; conservation, 143,900 acre-feet; and flood control, 337,700 acre-feet. The firm yield from the 143,900 acre-feet of conservation storage is estimated to be 56 cfs, which is equivalent to about 36 mgd.

IV. DESCRIPTION OF STUDY AREA

Location and Boundaries

The area encompassed by this study is shown on Figure 2. The boundaries were chosen so as to include the entire area which might be served through one integrated plan, from reservoirs on the San Gabriel River, Millican Reservoir on the Navasota River, Somerville Reservoir on Yegua Creek, Stillhouse Hollow Reservoir on the Lampasas River, the existing Belton Reservoir on the Leon River, and the enlarged Lake Waco on the Bosque River. The major water demand probably will center in the vicinities of Waco and Freeport; therefore, the decision was made to make the length of the study area run roughly from Waco in the north to Freeport on the southern coast. The east-west boundaries generally follow the divide of the Brazos River Basin but are modified to some extent with consideration being given to the political boundaries which nearly coincide with this basin boundary. It was necessary to make the total study area boundary follow county or precinct lines in order to facilitate the use of U. S. Bureau of Census population data.

The total study area includes Limestone, Falls, Bell, Williamson, Milam, Robertson, Brazos, Burleson, Grimes, Washington, Waller, and Austin Counties. Also included are portions of McClennan, Lee Fort Bend, and Brazoria Counties.

Geography

In the lower Brazos River Basin, the terrain changes from rolling hills in the northern portion to a flat coastal plain surrounding Freeport in the southern section. The table-like topography of the alluvial plain along the main channel of the Brazos River does not afford economical reservoir construction sites. 2/ The flood plain has extensive agricultural development, many highways, railroads, and communities which deter the possible use of this area for reservoirs. For the above reasons, the reservoirs (existing and planned) previously mentioned as being possible surface water sources for the area are located a number of miles upstream from the major potential water customer -- that is, the industrial complex centered around the city of Freeport.

The study area has four major soils regions within it. 3/ Traveling from north to south, one would encounter them in the following sequence: the Grand Prairie which has stony clays overlying

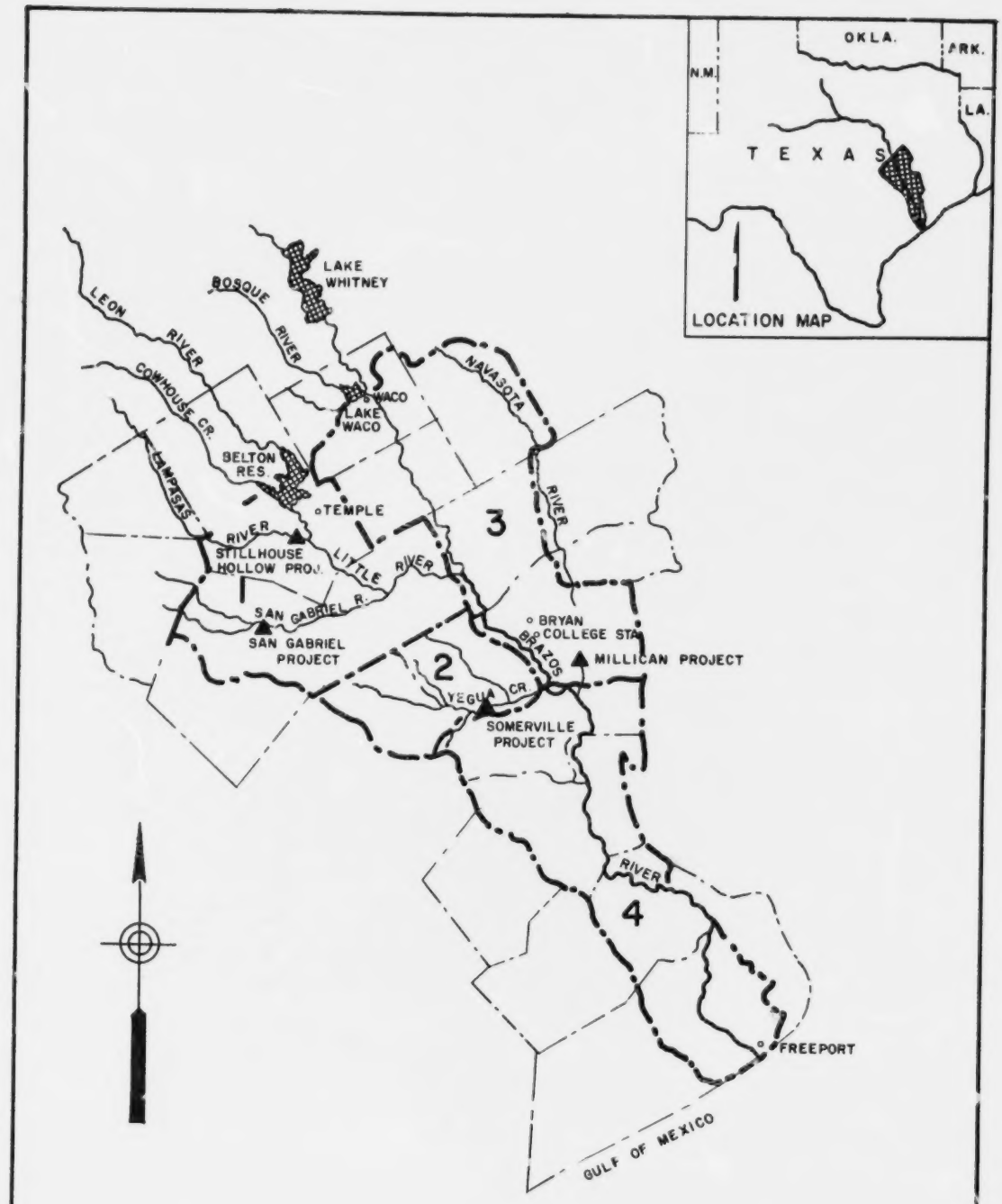

OKLA.
ARK.
N.M.
LA.
TEXAS
LOCATION MAP
LAKE WHITNEY
BOSQUE RIVER
LEON RIVER
COWHOUSE CR.
WACO
LAKE WACO
NAVASOTA RIVER
BELTON RES.
TEMPLE
CAMPSEAS
RIVER
STILLHOUSE HOLLOW PROJ.
LITTLE RIVER
SAN GABRIEL R.
SAN GABRIEL PROJECT
BRYAN
COLLEGE STA.
BRAZOS
MILLICAN PROJECT
YEGUA CR.
SOMERVILLE PROJECT
RIVER
3
2
4
FREEPORT
GULF OF MEXICO
NO SCALE
WATER RESOURCE STUDY
YEGUA CREEK
POTENTIAL DEMAND AREA
LOWER BRAZOS RIVER
DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII
DALLAS, TEXAS

FIGURE 2

limestone; the Blackland Prairies which are composed of dark clays; the East Texas Timberlands with sandy soils underlain by rock; and finally, the Coast Prairie composed of clay and clay loams. These lands are used for many purposes. A few examples are the production of grains, grain sorghum, corn, cotton, alfalfa, timber, truck crops, and rice.

The Brazos River flows in a general southeasterly direction through this area to the Gulf of Mexico. The slope of the river bed varies from approximately 1.2 feet per mile near Waco to less than 0.5 feet per mile near the Gulf. The average flow over 35 years of record at Richmond has been 7,173 cfs, as measured by the U. S. Geological Survey. At Juliff, a city below Richmond, the river has been dry at times due to heavy pumping withdrawals. 4/ The records of both gaging stations reflect the effect of regulation by upstream reservoirs.

Climate

The lower Brazos area is characterized by a mild and fairly uniform climate. The mean annual temperature varies from about 70 degrees in the coastal area to 66 degrees in the vicinity of Waco. 5/ From Waco to the Gulf Coast, the normal rainfall varies from 33 inches to 47 inches annually. 5/ The average length of the growing season ranges from 260 days in the northern portion to 320 days near the coast. 5/

Principal Communities and Industries

Urban centers within the study area which exceeded 10,000 population in 1960 are Temple, Killeen, Bryan, College Station, Waco, and Freeport. These major urban centers, along with the rest of the organized communities which would have public water supply systems, were included in this study.

The principal industries found in this area are agriculture, petrochemical manufacture, oil production, sulfur mining, and stone, clay, and glass products manufacture.

V. ECONOMICS AND POPULATION

Economic Base

General

To determine the probable future economic situation of the study area, an analysis of the raw material base, population change factors, and locational economic factors has been made, taking into account regional expectations.

Extractive Industries

Mining

Oil and natural gas production is of major importance in the Gulf Coast portion of the lower Brazos area. Austin, Brazoria, and Fort Bend Counties are among the Nation's largest producers of oil and gas. 6/ Also, in the southern area, there are sulfur mining activities, and magnesium is being extracted from seawater. In the northern segment of the area surrounding Waco, there are sand and stone quarrying and coal mining.

Agriculture

Agriculture is one of the most important activities and is practiced, to some extent, over the entire area. However, it is most important in supporting the economies of Brazos, Burleson, Grimes, Lee, Milam, Robertson, and Williamson Counties. The aggregate acreage of cropland harvested in these particular counties was 781,808 in 1944; 793,605 in 1949; and then fell to 746,371 acres in 1954. 7,8/ For these same years, the value of all farm crops sold showed a steady increase from $13,319,000 to $22,906,000. 7,8/ In 1944, the value of livestock and livestock products sold was $12,155,000; this figure rose to $13,993,000 in 1954. 7,8/ The agricultural value figures shown here have been adjusted to compensate for the change in the value of the dollar since 1944.

Manufacturing

In the northeast section of the study area, manufacturing plays the paramount role in the economy. In 1954, the counties of Bell, Brazos, Limestone, and McClennan had 61 per cent of the total number of manufacturing firms located in the 16-county lower Brazos River area. 9,10/ This four county segment had 210 firms in 1947 and 250 firms in 1954. 9,10/ In this segment of the study area near Waco, firms are concerned with the manufacture of stone,

clay, glass and rubber products. The manufacture of furniture, apparel, and paper products is also important here. In addition, an alumina reduction plant is located here. In the southern section, the manufacture of petrochemicals on a very large scale is probably the most important single item in the manufacturing activity of that area.

Population

The projected population given herein for the entire lower Brazos River area includes all people who live in organized communities (which have public water supply systems) and excludes those living outside such cities. This population has shown a trend of steady growth in the period from 1930 to 1960. In 1930, the total municipal population was 164,300 and by 1960 this figure had risen to 340,000. 11/ A trend toward urbanization is illustrated by the change in the relative numbers living in cities and towns; in 1930, 34 per cent lived in the municipalities: and by 1960, it was an estimated 57 per cent. 11/

The historical population data for each of the four subdivisions as shown on Figure 2 of the study area are shown in Table 2.

Table 2 11/

Past Populations

Sub-Area	YEAR 1930	1940	1950	1960
1	47,101	47,602	69,107	93,521
2	6,365	6,483	6,669	6,674
3	90,136	103,758	147,816	167,678
4	20,712	27,297	47,610	72,089
TOTAL	164,314	185,140	271,202	339,962

Future Growth

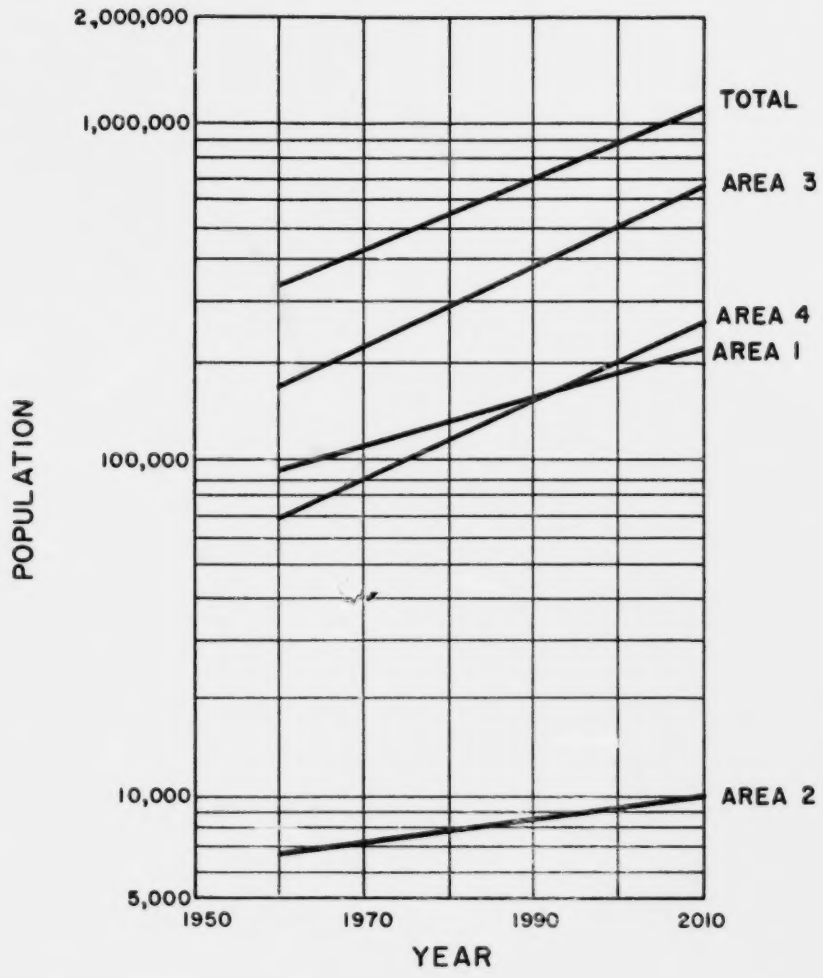
Growth Factors

The future expansion of the economy of the area will depend upon the growth potential of its various segments. In agriculture, the production of crops, livestock, and livestock products is expected to increase only slightly, but the number of agricultural employees will decline due to further mechanization. Increases in food processing can, however, be anticipated. It is expected that the manufacturing industries producing stone, clay, and glass products near Waco will enjoy substantial growth because of the availability of supplies of raw materials necessary for the operation of

these industries. The manufacturing activities in the Waco area may also show accelerated growth from the already present base because of expectations that the markets for these products will expand. Farther south, in the area between Rosenburg and Freeport, it is forecast that the petrochemical industries will show a tenfold production increase in the next 50 years because of the plants already located there and the plentiful supply of oil and gas in the area. The magnesium extraction might also expand, since all the necessary materials for production are present locally.

Population Projections

Population projections were made for each of four subdivisions as shown on Figure 2 of the study area. The four trends and a projection for the total area are shown on Figure 3. In making these projections, consideration has been given to published documents, 6/ historical growth patterns, and information obtained in field investigations. They are influenced also by the analysis of future economic growth just described.



WATER RESOURCE STUDY
YEGUA CREEK

LOWER BRAZOS RIVER AREA

POPULATION TRENDS

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

12b

FIGURE 3

VI. WATER REQUIREMENTS

General

The gross requirements considered in this study were separated into industrial and nonindustrial water users. Industrial water, as the term is used herein, is water used by basic industries (those which produce goods which are sold outside the area and thus bring income into it). Nonindustrial water is that water used for functions other than those performed by basic industries. The requirements are indicative of gross intake by the water users and do not reflect the fact that a portion of the water used by upstream consumers will be returned to the stream -- eventually to be re-used by downstream water customers.

Past Water Use

Shown in Table 2 are the approximate quantities of water used for nonindustrial and industrial purposes during the year 1958. The nonindustrial water requirements were prepared through the use of the previously discussed populations and nonindustrial per capita water consumption figures. An average per capita consumption use of 120 gpcd (gallons per capita per day) was used for the entire area in 1958. This is an average based on data reported to the Texas State Department of Health by typical cities in the area. The 1958 industrial water use data shown were obtained from the Bureau of Business Research, University of Texas, which made a survey of water used during that year. The industrial water use figures shown in Table 3 cover over 90 per cent of all industrial water utilized in the area in 1958.

Table 3

Past Water Use (1958)

Sub-Area	Appraised Population	Nonindustrial Use (gpcd)	Average Annual Water Use (mgd)	
			Nonindustrial	Industrial
1	90,000	120	10.8	5.5
2	6,700	120	0.8	0.01
3	163,000	120	19.6	1.9
4	66,500	120	8.0	181.0
	326,200			

Estimated Total Use, 1958 -- 227.6 mgd

Existing Sources

Quantity

The surface and ground water resources of the lower Brazos River Basin can, as soon as the modification to the existing Lake Belton is completed, furnish approximately 210 mgd of dependable supply to the users in this area. Lake Waco and Lake Belton are presently the chief surface water sources in this area and together are capable of potentially furnishing an estimated 160 mgd. It is estimated that the underground sources of water are capable of supplying approximately 50 mgd to municipal and industrial users, thus bringing the total yield of present supplies in the area to 210 mgd.

It should be noted that the estimated yields of the surface water impoundments discussed in this report are for only water supply (conservation) storage volume included in each reservoir. A portion of these yields from this conservation storage space is presently allocated to meet irrigation needs. It is infeasible at this time to estimate whether an increase or a decrease will take place in the volume of water allocated to irrigation uses. It should also be noted that capability of ground water discussed herein refers to just that amount which is and could be developed for municipal and industrial uses.

Quality

According to records of the Texas State Department of Health, the mineral and organic quality of the water in the Bosque River (on which Lake Waco is located) is generally acceptable for industrial and municipal uses. With respect to mineral and organic quality, the same may be said for the Little River, in whose watershed Lake Belton is located.

The high mineral concentrations prevalent in the water of the main channel of the Brazos River above Lake Whitney place severe limitations on using it for municipal and industrial purposes. These high concentrations are caused by salt springs and gypsum outcroppings located upstream from Lake Whitney. Table 4 shows data collected by the U. S. Geological Survey.

As the water in the main stem moves downstream, higher quality water with lower concentrations of minerals enters from tributaries and dilution takes place. The effects of this dilution water on the concentrations of chlorides and sulfates may be seen by comparing Tables 4 and 5. The data shown in Table 5 are also from records of the U. S. Geological Survey.

Table 4 12/

Chemical Quality - Brazos River Near Whitney, Texas

Water Year	Mean Daily Discharge (cfs)	Weighted Average Concentrations (ppm)	
		Chlorides	Sulfates
1948-49	1,566	242	172
1949-50	1,520	244	157
1950-51	840	437	260
1951-52	348	332	167
1952-53	141	209	112
1953-54	912	392	198
1954-55	997	374	205
1955-56	1,571	333	255
1956-57	6,213	126	96

Table 5 12/

Chemical Quality - Brazos River at Richmond, Texas

Water Year	Mean Daily Discharge (cfs)	Weighted Average Concentrations (ppm)	
		Chlorides	Sulfates
1948-49	4,645	103	76
1949-50	5,783	87	58
1950-51	1,418	214	134
1951-52	1,820	85	54
1952-53	4,105	31	25
1953-54	2,727	127	72
1954-55	2,168	145	83
1955-56	2,185	260	185
1956-57	15,290	65	54

As shown by comparison of Tables 4 and 5, the chemical quality of the water in the main channel of the Brazos River improves as the water flows downstream and is diluted with water from tributary streams. Nevertheless, the concentrations of chlorides and sulfates as far downstream as Richmond are, at times, still high enough to produce water of

mediocre to poor quality. Unless the upstream sources of mineral contamination are effectively eliminated, the quality of the Brazos water above Lake Whitney will remain at such a level as to make questionable a decision to use this water for municipal and industrial purposes. Studies made jointly by the Brazos River Authority, the Texas Board of Water Engineers, and the U. S. Geological Survey have located the sources of contamination. It is concluded that the water quality impairment by these sources will be reduced and that the chemical quality of the Brazos River water will improve in the future. This should make possible the utilization of a substantial portion of the runoff in the main stem, which averages about 1,100 mgd above Waco, Texas. In addition, serious consideration should be given to operational plans for proposed reservoirs on tributaries so that they will create the optimum quality of water in the main channel of the Brazos River for the highest type of use possible.

From a discussion in Texas Water Resource Planning at the End of 1958, [3] it is apparent that the ground-water quality in the study area varies from one aquifer to another and even within one particular aquifer. There are seven major and three minor water-bearing formations in the area. Within the Edwards limestone, Catahoula-Oakville-Lagarto, and Goliad-Willis-Lissie sands, the quality of the ground water is generally acceptable for municipal and industrial purposes. The water of the Trinity and Beaumont sands is of such quality that it can be termed reasonably satisfactory for most uses. The water contained by the Woodbine sands is characteristically hard. The location of good quality water in the Carrizo-Wilcox sands is unpredictable and spotty. The Mount Selman sands, which overlie the Carrizo-Wilcox formation, hold water with a quality not as good as the Carrizo-Wilcox water.

Additional Water Needs

Nonindustrial and Industrial

The nonindustrial water requirements for this area were prepared through the use of the previously mentioned projected populations and nonindustrial per capita water consumption figures. In 1985 and 2010, the per capita water consumption figures are an average of data obtained after study of preliminary U. S. Study Commission work papers and a publication entitled Water for the Future [6] by the Bureau of Business Research, University of Texas.

The projected industrial water requirements were obtained after careful consideration of the growth potential in 16 of the basic industrial categories which use over 90 per cent of the industrial water

in the area. The present level of development in each category was compared to development on a national level, so as to obtain an indication of the relative share of the national market that each category holds. Those industrial categories which have less than their share of the national market were projected at a higher rate of growth than expected nationally. Those categories which have more than their share of the national market are expected to maintain their relative percentages of the market in the future. Once a trend in production was assumed for a particular industrial group, a trend in water use was projected. The water use trend, expressed as water requirements per unit of production, was lowered for industries that are large water users in anticipation of more efficient water use (i.e., cooling towers and other methods of cooling). Data collected in the field were utilized in making these projections. In addition, trends in production and water use as shown in Water Resources Activities in the United States 13/ were studied.

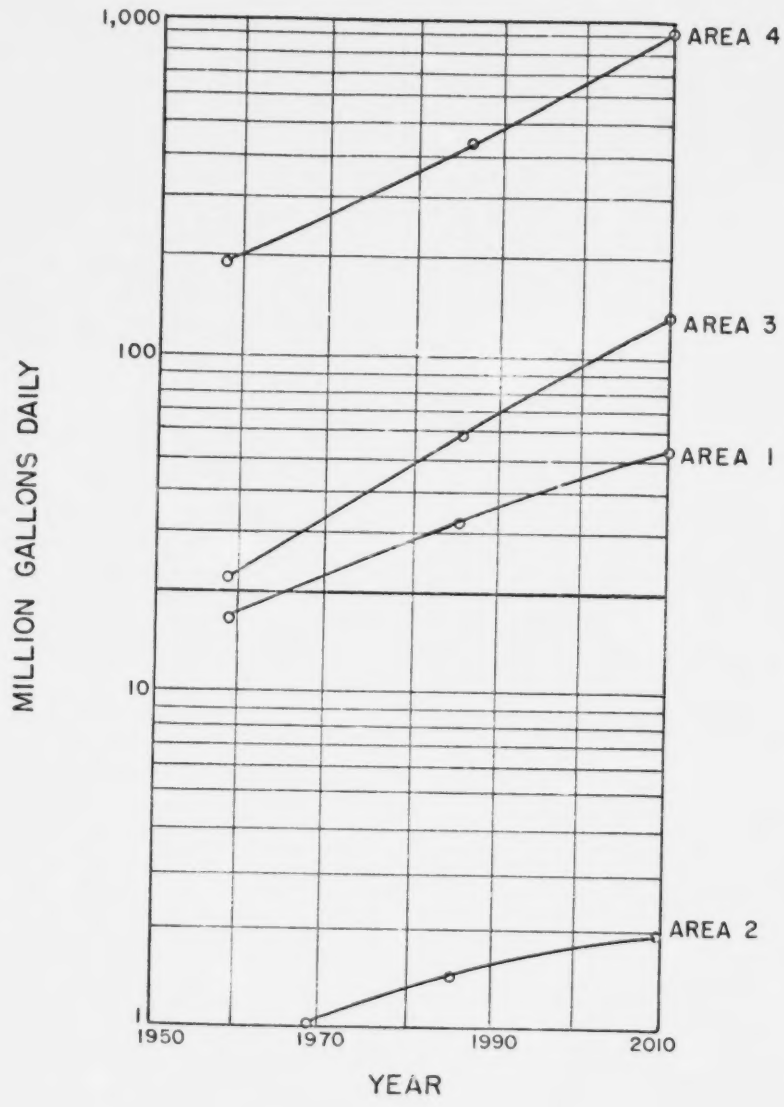
By reference to Table 6, one can see the basic information necessary to the formation of Figures 4 and 5.

Stream Quality Maintenance

Protection of the quality of Texas waters is primarily the responsibility of the Texas State Department of Health. Stream quality criteria and subsequent regulations governing waste discharges, and other pronouncements on the maintenance of water quality within State boundaries, come from this agency. The use of water will almost inevitably result in the production of some liquid wastes which, even after a high degree of treatment, may degrade the quality of the receiving stream. It is essential that recognition be given to the need for flows which must be maintained in the receiving stream, even after a high degree of treatment, if the quality of its waters is to be kept at reasonable levels.

Within the drainage area of the proposed Somerville project, there are several creeks which are receiving treated wastes from the cities of Rockdale, Lexington, and Giddings. The present waste treatment facilities of these cities consist of primary sedimentation, followed by waste-stabilization lagoons.

During the field investigation phase of this study it was determined that throughout periods of hot, dry weather the treated liquid wastes from the above cities are lost to evaporation and channel seepage before they enter the proposed reservoir area. During periods of heavy surface runoff, it is estimated that these treated liquid wastes make up much less than 10 per cent of the volume of total surface runoff. For these reasons, it is concluded that these treated wastes from Rock-



WATER RESOURCE STUDY
YEGUA CREEK

SUBAREA
WATER REQUIREMENTS

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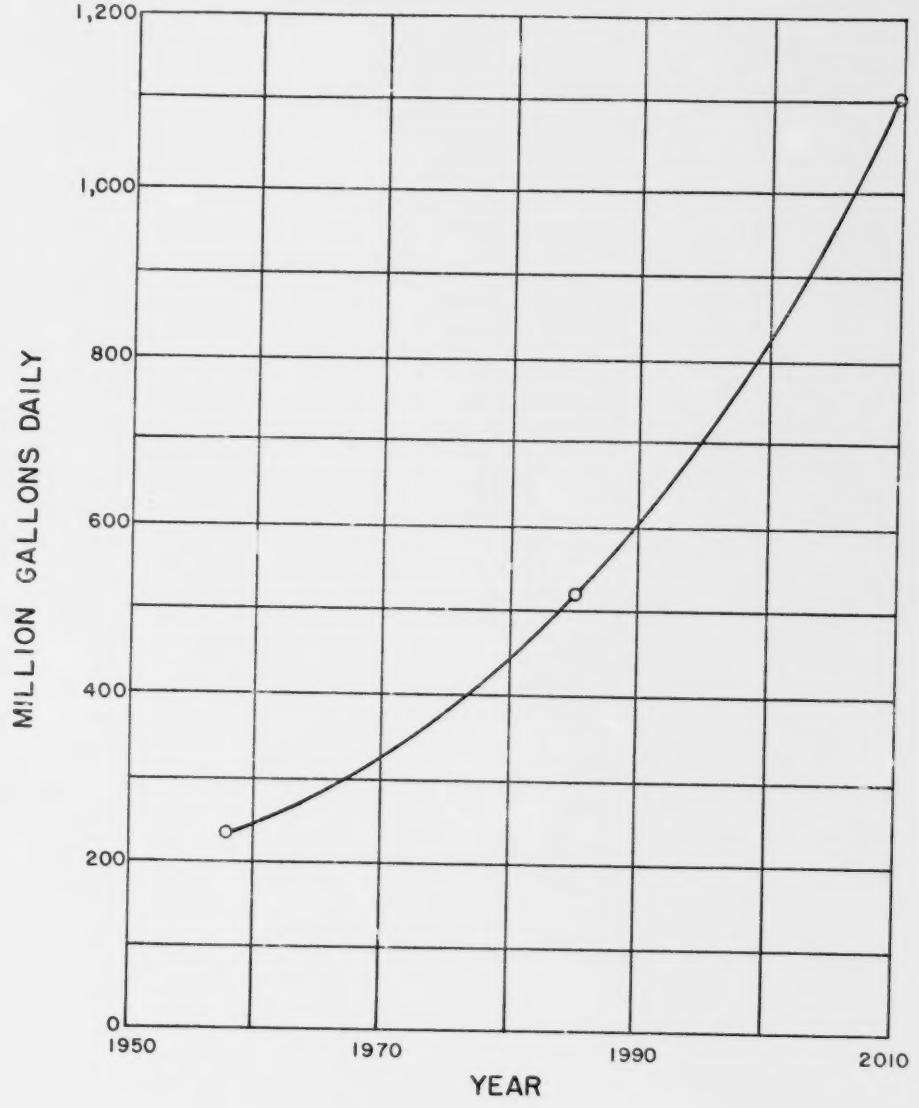
FIGURE 4



WATER RESOURCE STUDY
YEGUA CREEK

TOTAL MUNICIPAL & INDUSTRIAL WATER REQUIREMENTS

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FIGURE 5

dale, Lexington, and Giddings will not create any water quality problems, related to public health, recreation, or aesthetics, within the confines of the proposed Somerville Reservoir. The only problems these wastes might cause will be of minor and local significance related most probably to aesthetics. These problems, if they arise, can be minimized if not eliminated by proper design, operation, and maintenance of the waste treatment facilities in the area.

Table 6

Lower Brazos River Area Water Requirements

Sub-Area	Population	Nonindustrial Use (gpcd)	Average Annual Water Requirements (mgd) Nonindustrial	Industrial
		Year 1958		
1	90,000	120	10.8	5.5
2	6,700	120	0.8	0.01
3	163,000	120	19.6	1.9
4	66,500	120	8.0	181.0
	326,200	Estimated Total Requirements, 1958 - 227.6 mgd		
		Year 1985		
1	143,000	162	23.2	9.7
2	8,300	153	1.3	0.06
3	330,000	162	53.5	4.3
4	136,000	149	20.3	406.0
	617,300	Estimated Total Requirements, 1985 - 518.4 mgd		
		Year 2010		
1	213,000	190	40.5	13.0
2	10,200	170	1.7	0.2
3	660,000	190	125.4	7.3
4	260,000	165	42.9	870.7
	1,143,200	Estimated Total Requirements, 2010 - 1,101.7 mgd		

In the reach of the Brazos River between Waco and a point near river mile 20 (which marks the approximate limit of upstream intrusion into the main channel by sea water), the disposal of treated organic wastes produced by the population in the area and to some extent by chemical industries could degrade the water quality. Stream flows should be maintained at a level sufficient to assimilate the treated wastes in order to avoid such quality impairment. It is assumed that these organic wastes will be treated for the removal of 90 per cent of the BOD (biochemical oxygen demand). Studies are now underway which will furnish estimates of the amounts of water needed to maintain quality objectives after the wastes are treated. These studies are being made as a part of a comprehensive consideration of water quality in Texas intrastate streams for the U. S. Study Commission - Texas. Water quality data being collected by the Texas State Department of Health will be fully utilized in these studies.

In the reach of the Brazos described in the preceding paragraph, the manufacture of stone, clay, glass, rubber, etc. are the most prevalent types of industrial activities. The existing manufacturing processes do not produce large amounts of organic waste. It is assumed that the mineral wastes resulting from future manufacturing, which is expected to be in the primary metals, will be disposed of in such a manner that no adverse stream conditions will be created.

The petrochemical industry is expected to expand tenfold within the next 50 years along the Gulf Coast of Texas. The segment of the Brazos River which will be affected by the large amounts of wastes from this industry will be principally the area where sea water intrudes the fresh water of the Brazos River. The usefulness of this estuarial water is already impaired by high concentrations of mineral solids, such as chlorides, on incoming tides. Based on the known characteristics of wastes from the petrochemical industry, it is assumed that their mineral solids content will cause no significant change in the receiving waters. Therefore, it is assumed that if the organic constituents of these wastes are given adequate treatment and no waste components are present in toxic concentrations, the usefulness of receiving waters into which the wastes are discharged will not be impaired. This is true because a major portion of the water demand in this area is for cooling purposes, for which it is possible to use a water with a relatively higher mineral content than would be suitable for municipal and industrial process purposes.

The foregoing statements are subject to qualification in the event that a salt-water barrier is built to bring the high quality fresh water channel closer to the coast. In that case, it may be necessary to divert treated industrial wastes to a separate channel.

Plan for Supplying Future Requirements

The present sources of water supply for municipal and industrial purposes in the study area are primarily Lake Waco, Lake Belton, and ground water. The ultimate capabilities of the surface water sources are: Lake Waco, 55 mgd and Lake Belton, 105 mgd. The present level of development of ground water is 50 mgd. The quality of the water obtained from these sources has been discussed previously in this report. Somerville Reservoir with its yield of 36 mgd from conservation storage would bring the total water supply available to approximately 246 mgd.

The total intake requirements of municipal and industrial water users in the lower Brazos River Basin are projected to be 1,102 mgd by the year 2010. The major portion of this demand (914 mgd) is expected to develop in Subarea 4.

The total water requirements mentioned above are much greater than the amounts of water that the existing sources plus Somerville Reservoir will be able to supply. Therefore, it is necessary to plan for additional water supplies and to study the supply and demand balance of the lower Brazos River area. The existing and proposed supplies considered in this plan are presented in Table 7.

Table 7

Existing and Proposed Water Sources - Lower Brazos River Area

Source	Estimated Yield (mgd)
Lake Waco (existing enlarged)	55
Lake Belton (existing enlarged)	105
Stillhouse Hollow Reservoir (proposed)	63
San Gabriel River Project(s) (proposed)	53
Millican Reservoir (proposed)	226
Somerville Reservoir (proposed)	36
Ground Water (present development)	50
Ground Water (future development)	67
TOTAL	655

It can be concluded from comparing the expected total water requirements of 1,102 mgd by 2010 with the total estimated yield of 655 mgd, that a demand exists for the maximum feasible amount of municipal and industrial water supply storage that can be economically developed in the proposed Somerville Reservoir.

The water supply deficit indicated above is partially offset by the fact that the demand figures represent gross takeout from sources, a portion of which will be returned to the stream for subsequent re-use. However, this compensating effect is minimized because approximately 800 mgd of the total demands of the area are expected to originate near the mouth of the river. Additional measures will be required to increase the dependable supply, if growth is to occur as projected. In this connection, it may be noted that a regulated surface supply of 538 mgd is a small part of the average annual runoff of about 4,600 mgd in the Brazos near Richmond, Texas.

VII. BENEFITS OF STORAGE

General

The preceding sections of this report have shown the projected water needs of the lower Brazos River area, and the physical feasibility of meeting a part of the needs by storage in the multiple-purpose projects under study. The question of economic feasibility leads to consideration of the monetary value, or benefits, of water supply storage.

It has been said that the limiting value of works constructed for the improvement of water supply is the maximum amount prudent users would be willing to pay for the improved or augmented service. However, precise measurement of benefits on this basis is difficult, if not impossible. The concept serves to place a ceiling (based on judgment) on the value of storage determined by the "alternative-cost" method.

The Alternative-Cost Doctrine

The 1958 report 14/ of the Subcommittee on Evaluation Standards states: "From an overall public viewpoint, a ... water supply development will be economically justified if it provides water to meet expected needs at a cost not greater than the cost of the alternative source that would likely be utilized in the absence of the project." Applied to the problem at hand, the stumbling block in this quotation is the word "source."

In the overall picture, it seems certain that the increasing need for firm water supply in the lower Brazos Basin will first be met by additional impoundments of the runoff within the basin and further development of the area's ground-water resources. It is not reasonable to assume that this water would be allowed to escape to the Gulf while other water was imported from, say, the Mississippi River. (This is not to be interpreted as ruling out the possibility of interbasin transfer of water.)

Nevertheless, the alternative-cost principle may be applied. Although there is considered to be no alternative water, there are ways to impound it other than by multiple-purpose projects. Unless otherwise qualified in what follows, the word "Project" will mean the system of six Federal reservoirs, Stillhouse Hollow, Somerville, Millican, North San Gabriel, South San Gabriel, and Laneport. In like manner, the word "Alternate" will refer to a hypothetical system of reservoirs which might, in the absence of the Project, be built for water supply only.

Alternative Plan for Water Supply

Meeting the water needs of the study area will apparently require the impoundment of water on each of the major tributaries of the lower Brazos. From a regional standpoint, no single reservoir can be regarded as an alternate to any other, because all will be needed. Hence the decision to look at all six together. The alternative is comprised of six single-purpose dams located at the same sites as the Corps projects, each having a firm yield equal to that of the project dam. These sites are not the only possible ones for accomplishing the purpose, and validity of the method does not require that alternative sites be the same as project sites. They have been selected for convenience, because of known physical feasibility, and because detailed information for analysis is readily available.

The Fort Worth District Office of the Corps of Engineers furnished estimates of the cost of construction of each single-purpose dam. Table 8 shows these costs and corresponding annual costs. The latter include operation and maintenance costs. For converting capital costs to equivalent annual costs, an economically useful life of 50 years and a non-Federal interest rate of 4 per cent were assumed.

Each of the aforementioned annual costs is considered to be the minimum annual benefit from water supply storage at the site, from and after the date on which the site might first be needed in the alternative plan.

Sequence of Construction

Although there is no reasonable doubt that all dams in the system would be needed in less than 50 years, it is equally clear that not all are needed now. For subsequent use, it is necessary to assume a sequence of construction and date of first utilization of each dam in the alternative system. Mathematically, there are 720 possible combinations of the six dams.

The problem of adopting a schedule of sequence and date of construction involves a number of factors. There is a wide diversity in the sizes of individual reservoirs, with yields ranging from 11 to 226 mgd. As might be expected, the unit cost per thousand gallons of potential yield varies inversely with the capacity.

The sequence which gives the lowest present worth of all future costs if that of scheduling dams in decreasing order of unit cost, i.e., from largest to smallest size. However, it is believed that

Table 8

Alternative Cost and 1965 Values

	Stillhouse Hollow	Somerville	North San Gabriel	Millican	South San Gabriel	Laneport	Sum or Average
Order of Construction	(1)	(2)	(3)	(4)	(5)	(6)	
Yield, mgd	63	36	19	226	11	23	378
Construction Cost, Single-Purpose Alternative	$12,220,000	$11,100,000	$8,250,000	$27,060,000	$5,860,000	$20,800,000	
Annual Capital Cost (50 yrs @ 4%)	570,000	517,000	384,000	1,260,000	273,000	970,000	
Annual O & M Cost	40,000	30,000	38,400	57,000	37,600	40,000	
Combined Annual Cost	$ 610,000	$ 547,000	$ 422,400	$ 1,317,000	$ 310,600	$ 1,010,000	
Unit Cost ¢/1,000 gals.	2.66	4.16	6.09	1.60	7.73	12.0	
Year of First Need	1960	1966	1970	1973	1990	1991	
Discount Period	0	1	5	8	25	26	
Present Worth Factor	1	0.962	0.822	0.731	0.375	0.361	
1965 Annual Value	$ 610,000	$ 526,000	$ 347,000	$ 963,000	$ 116,000	$ 365,000	$2,927,000
1965 Benefits in ¢/1,000 gals. yield	2.66	4.01	5.00	1.17	2.89	4.35	2.12

this is not necessarily the sequence most likely to be chosen. Building the largest dam (Millican) first would give the least favorable capacity factor (ratio of actual use to capacity) over the longest period of time.

At the opposite extreme might be a sequence from smallest to largest size. Reference to Table 8 will show that the smallest (South San Gabriel) would yield 11 mgd at a unit cost of 7.73 cents per thousand gallons. It seems likely that this unit cost would be higher than the ceiling price which the prudent user, mentioned in the introduction to this chapter, would be willing to pay. The engineer, making today a plan for meeting future water supply needs, would probably feel that it might some day be necessary to pay a price that high. But more than likely, he would defer that project as long as possible. Also, he would probably want to defer the single-purpose Laneport Reservoir because of its high unit cost, 12.0 cents per thousand gallons, and because of its unfavorable capacity factor.

To a somewhat lesser degree, the foregoing statements would apply to the North San Gabriel site. There, a reservoir to yield 19 mgd would cost 6.09 cents per thousand gallons. However, at this point, another facet of the problem should be considered.

A decision to defer construction of the dam on any one of the tributaries would involve the question of present need in the area immediately downstream on that tributary. Local areas which have been investigated are Georgetown and Taylor on the San Gabriel and Bryan-College Station and Navasota on the Navasota River. The present, and probable future, needs of Georgetown and Navasota can be met by ground water. Estimates of relative transmission costs indicate that Bryan-College Station could obtain water more economically from the main stem of the Brazos than from the Navasota River. However, the high mineralization at times found in Brazos River water may prohibit Bryan-College Station from using this watercourse as a source of water supply.

This leaves the Taylor area in which the ground water is too highly mineralized for satisfactory use. This poses a problem for Taylor for which no feasible answer is readily apparent unless storage can be provided in one of the San Gabriel multiple-purpose reservoirs at a cost substantially lower than the figures of 6 to 8 cents per thousand gallons. Otherwise, it is believed that some expedient would be found for meeting the relatively small needs of Taylor which would not require expenditure of several million dollars for a dam. For example, good quality ground water is available (from the Edwards formation) about eleven miles west of the city. Nevertheless, in consideration of the local area needs, especially Taylor, the North San Gabriel project has been inserted in the sequence for construction by 1970.

Translation of Alternative Costs to Multiple-Purpose Project Benefits

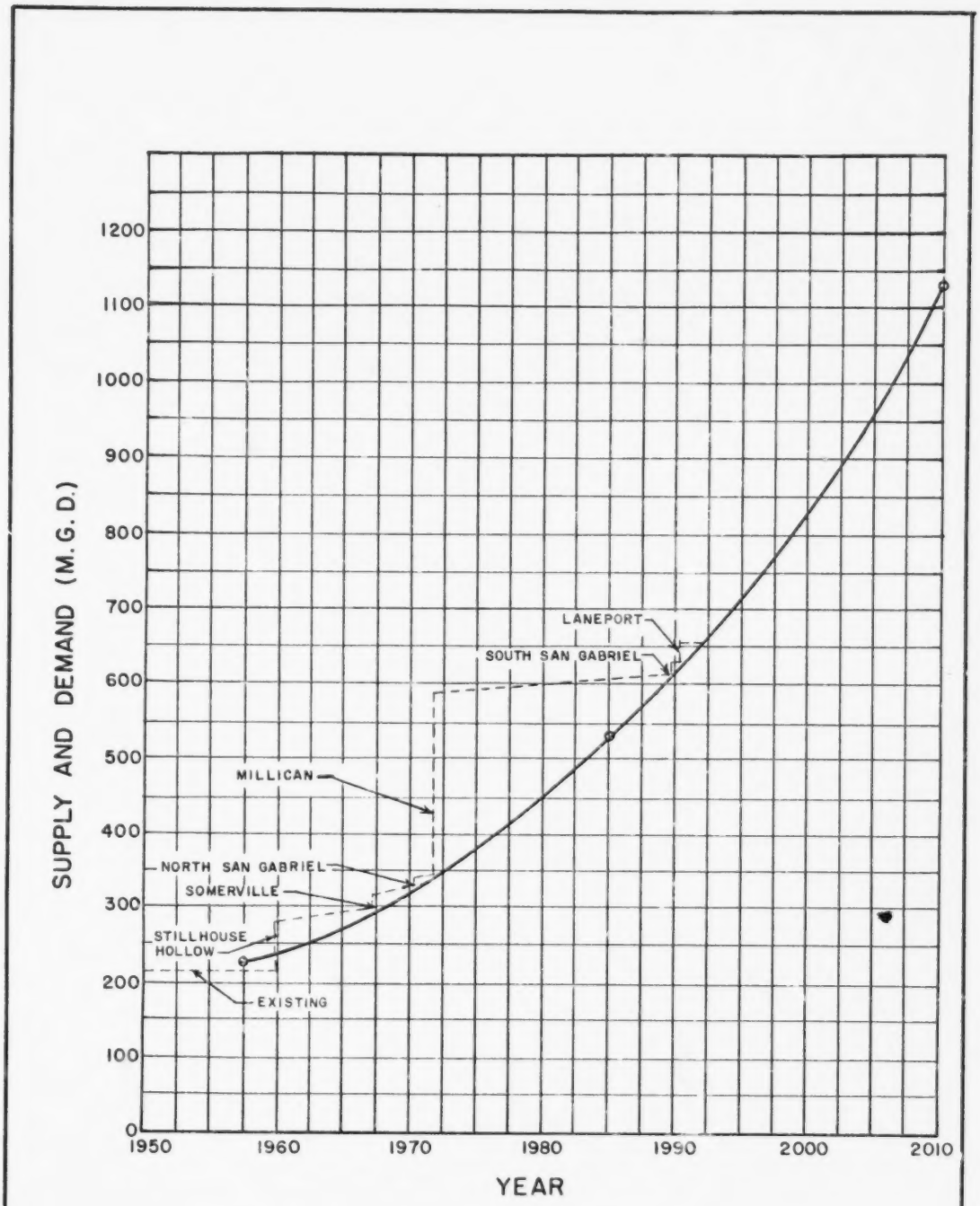
In spite of complexities and uncertainties, it is essential to formulate an alternative plan for the objective of determining the value of storage in the project. To this end, the sequence of construction of the alternative dams has been assumed to be as indicated in Table 8. The year 1965 has been selected as the common time base to which all future benefits are discounted. Benefits have not been discounted when derived from single-purpose reservoirs which would be utilized in the adopted sequence in or before the year 1965.

The adjustment of future benefits was made by the method of capitalized costs, as described by Woods and DeGarmo in Introduction to Engineering Economy. 15/ Fundamental to the method is the assumption that the useful life of a reservoir extends over a 50-year period which begins at the date of first utilization. An interest rate of 4 per cent was used for discounting. Superimposing the yields on a graph of future water requirements, in the adopted sequence, gives the date of first utilization of each reservoir (see Figure 6).

The estimate that approximately 67 mgd of ground water will be developed in the future (in addition to present ground-water development) by municipal and industrial interests has been added to the hypothetical sequence at a constant rate over a period of approximately 32 years. This serves to explain why the curve representing potential sources (see Figure 6) is sloping between points of utilization of surface water impoundments.

The combined present value of storage in the alternative plan is about 63 million dollars. For a combined yield of 378 mgd, this reduces to a unit value of 2.12 cents per thousand gallons.

It is therefore concluded that the 1965 value of storage in the several reservoirs of the project will average at least 2.12 cents per thousand gallons of yield. Suggested individual values which make up this average are shown in Table 8.



WATER RESOURCE STUDY
YEGUA CREEK

FUTURE WATER REQUIREMENTS AND POTENTIAL SOURCES

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE 6

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